it is probable that much could be accomplished by doubling or tripling the number of the stations. It will, however, be of great importance to have a network of stations along the Pacific coast, with a closeness corresponding to that of the west coast of Norway, in order to be able to catch the arrival of lines of convergence, and thus determine as early as possible the direction which the cyclones will take. A close network of stations will probably also be useful on the Gulf coast.

Even if it might be desirable, it would not be necessary to give these new stations the same complete instrumental equipment as the old ones. Their most important task would be to give as accurate reports as possible:

I. On the direction and strength of wind, from which to determine the lines of flow.

II. On the temperature, from which to determine the sudden rise or fall at the lines of convergence.

Concerning further observations which may be desirable, e. g., concerning rain at or within sight of the station, on the appearance of the sky, etc., or concerning special observations which may be had from the coast stations and from favorably situated mountain stations, the reader is referred to my Gothenborg address.[3]

Concerning the advantages which might be obtained by this extension of the weather service it can be stated that if, as in western Norway, the observations in the morning are made the basis of forecasts for the rest of the same day, these forecasts may be given with great confidence and in great detail for the different districts, usually with an indication of the time of the day when the rain will begin.

It will be more difficult to express an opinion as to how forecasts for the following day, or a still longer period, would succeed. For in this field we have had no experience in Norway, where in the present abnormal conditions the duration of the forecast had to be limited to the utmost. But we have every reason to believe that conditions even in this respect will prove favorable on an area of observations of an extent as great as that of the United States.

It is of course very difficult for me to estimate the cost of the indicated change of the weather service in the United States. If, as I believe, a sufficient number of climatological stations already exist, the main expense would be on account of the increased telegraphic service.

It may be instructive to report that the Norwegian Government granted 70,000 kroner ($18,667) for experiment with the weather forecasting this past summer [1918] in western Norway according to the new system.

The main expense was for the telegrams, and the sum turned out to be sufficient for the purpose, even though it concerned a new start rather than an extension of a system already existing. The grant was given principally on the ground that even if there should result an increase of only 1 per cent in the returns from agriculture the expense given for the weather forecasting would be many fold covered.

[3] Pp. 90-95 of this REVIEW.

## SYNOPTIC STUDY OF HYDROGRAPHICAL PHENOMENA.

By Dr. HANS PETTERSSON.

[Dated: Göteborgs Högshole, Sweden, Dec. 24, 1918.]

In a previous communication[1] to the MONTHLY WEATHER REVIEW I have set out the reasons for an increased intensity of hydrographical observations in coastal waters and have also described some new technical resources evolved for that purpose.[2]

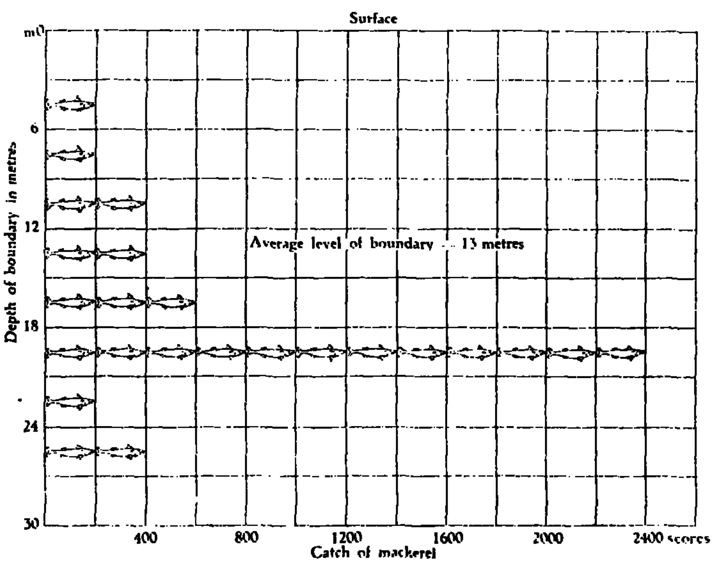


FIG. 1.—Relation of the catch of mackerel to the depth at which dense sea water is found.

Mainly through the daily soundings taken for nearly a decennium at Bornö Station in the Gullmarford, the first example of continuous hydrographical observations on record, the surprising variability of the situation in coastal waters was first proved and investigated. The close connection existing between similar changes and biological phenomena has repeatedly been confirmed by Swedish hydrographers, by G. Ekman and O. Pettersson for the rich catches of herrings made in winter off the west coast of Sweden and by the author for the catch of mackerel in summer. In figure 1 a graphical representation is given of the catches of mackerel made at Bornö during the summers of three years as a function of the simultaneous depth of the 30 per cent boundary in the fiord; nearly 1,000 scores were caught when the boundary was below its average level against less than 1,000 scores when it was above the average.

In winter, when these movements are especially large and rapid, the disappearance from the surface of water of North Sea origin (warm and salt) replaced by a sheet of ice-cold brackish water from the Baltic, or vice versa, will have a marked effect on the local air-temperature, the freezing of the fiords or the breaking up of their ice. The great scientific interest which these internal movements in the sea command is thus further enhanced by their bearings on practical questions.

Now the results from the investigation at Bornö are open to the objection that the displacements of the boundary observed at that place may be a *local* phenomenon limited to the Gullmarfiord—i. e., of the nature of the internal seiches studied in Scotch lochs by Wedderburn.[3] The best method of proving or disproving this suggestion is obviously to make continuous observations at one or more other points on the coast parallel to those at Bornö. A first attempt in this direction was made by the author

[1] MONTHLY WEATHER REVIEW, 1917, p. 159.

[2] The new Amundsen N. polar expedition has been equipped with a set of these instruments, its hydrographer, Dr. Sverdrup, studying their use at my institution before starting.

[3] Proc. R. Soc. Edinb. Vol. 29, p. 98.

in November, 1915. Exceptionally stormy weather which then prevailed prevented the observations from attaining the degree of completeness desired. At three of the points of observation, situated in the open sea, soundings could only be taken every third day, and at the fourth and last point besides Bornö, the lightship *Grisbåden*, soundings were taken once daily. The method employed was the rather cumberson way of titrating water samples collected by the water bottle. However, the results gave fairly good evidence that the larger displacements of the boundary, lasting for several days or more, form a part of a general phenomenon comprising the whole coast of Bohuslän. Besides, hydrographical changes of less amplitude and shorter duration were also apparent.

During two months of last summer a new attempt was made by the author to establish a system of "synoptic" observations at three different points on the coast of Bohuslän, viz, at Bornö, at Hättan, to the north of Marstrand, and at Böttö lighthouse outside Gothenburg. (See fig. 2.) The distance between the second of these places and each of the two others is about 50 kilometers. At all of them "U-tubes" or hydrostatic densimeters[4] were put up, by means of which any change occurring in the average density of a column of water extending from the depth of 1 meter below the surface down to a certain depth, D, can be observed in the simplest way possible. The depth D, which represents where the lower orifice of the hydrostatic system is placed, amounted to 25 meters at Bornö and at Hättan, whereas in the shallow waters round Böttö only 20 meters could be attained.

At the two places last mentioned there is always somebody on duty day and night, so thatt he instruments could be read regularly at intervals of six hours, viz, at 2 a. m. 8 a. m., 2 p. m., and 8 p. m. At Bornö readings were only taken in daytime, from 8 a. m. to 8 p. m. every third hour. To obtain a record of such completeness by means of the older technique would have involved a large amount of qualified labor.

The records from all three places are reproduced in figure 3, where the readings of the U-tubes are plotted against time, a rise in the curves corresponding to an upheaval of the boundary and vice versa. The scale is, of course, arbitrary, but a simple calculation shows that a change in the readings of 1 centimeter should correspond to a vertical displacement of the boundary of about 30 centimeters, or to a variation in the average density of the water column between 1 and 20 meters depth of about 0.0002.

A strong gale in the middle of August disconnected one of the lead tubes at Hättan. The records from Bornö and Böttö are given for a few days longer.

It is seen from the curves that considerable vertical displacements of the boundary have been going on almost without rest the whole time the investigation lasted. The similarity between the curves is very marked, especially between the curves from Börnö and Hättan, practically every large upheaval or subsidence in one of them being also visible in the other. The curve from Böttö, although it has many conformities with the two others, shows in general variations of less magnitude and has a flatter appearance. Especially during the middle of July it is almost devoid of "waves."

To a certain extent this discrepancy may be due to the relatively small value of the depth D, 20 meters at Böttö. Changes in the density between that depth and 25 meters would not affect the U-tube at that place, but would be recorded at the two others. Apart from that the geographical position is also different, Bornö and Hättan being both situated well within the outer skerries, whereas Böttö is almost out in the open sea. Now, both from a theoretical point of view and according to previous experience the internal movements should have smaller amplitude some distance off the coast than within the fiords.

Another fact, of the greatest interest, borne out by these curves, is that the internal movements observed at places so differently situated occur practically at the same time. This coincidence makes it extremely improbable that these movements can be due to any progressive boundary wave-motion proceeding either parallel or at an angle to the coast line. If the phenomenon is at all of an undulatory character, it must be of the

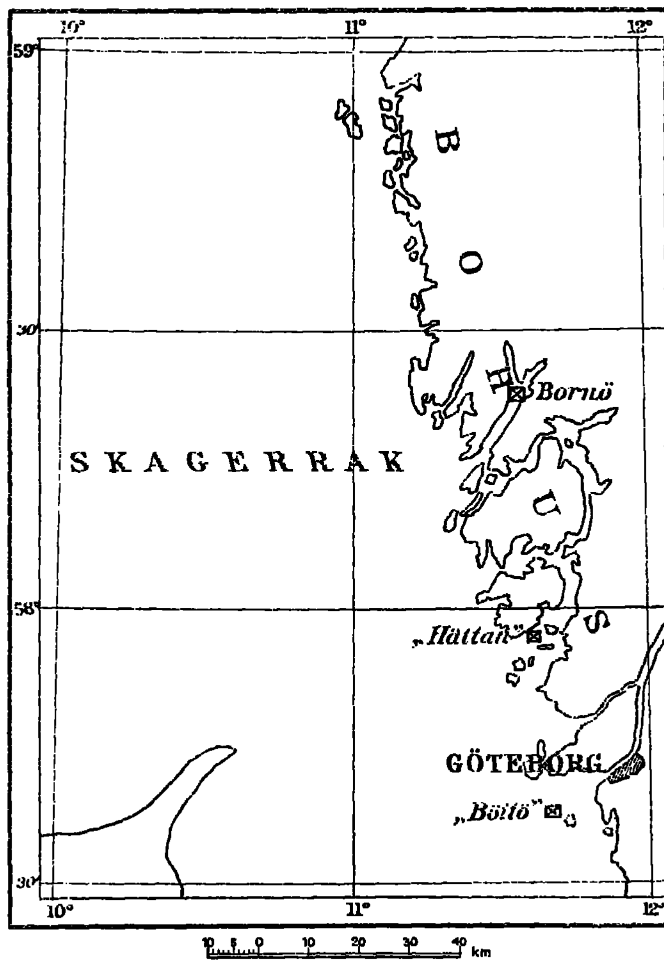


FIG. 2.—Map of west coast of Sweden.

standing wave type with a node line more or less parallel to the coast. A progressive boundary wave should have a velocity of the order 0.50 meters per second, so that it would take about 12 hours to travel up the Gullmarfiord to Bornö.

A close scrutiny of the record, however, seems to indicate that the coincidence between the larger waves and troughs is not absolute, but that there is a small lag between the Bornö curve and the two others. A rough calculation shows that the Bornö curve is on an average 3 hours (±1 hour) behind that of Hättan, and 4 hours (±2 hours) after Böttö. This difference in phase being considerably smaller than the interval between two readings, its very existence must be open to some doubt. Nevertheless, it seems reasonable that the displacement

[4] MONTHLY WEATHER REVIEW, Ibid. p. 160

of the boundaries, whether it is caused by a standing wave or not, may be somewhat retarded by the friction of the horizontal currents against the comparatively shallow treshold at the entrance to the Gullmarfiord.

As regards the details visible in the curves, i. e., the variations of shorter duration and small amplitude, they are seen to be individually different at the different localities. But they are seen to be especially prominent in all three curves during the first week of August, when they also tend to show a diurnal periodicity. In the Hättan curves they are followed by a set of still shorter waves of semidiurnal period. The latter period also crops up in many other parts of the records, and there is little doubt as to its tidal character. As there were no observations made of the surface tides, it can not at present be decided whether these were in phase with the boundary waves, i. e., if these latter were primary or secondary tidal boundary waves, the latter type having already been studied in the Gullmarfiord by Zeilon.[5] Observations similar to these but of greater frequency will have to settle this question. It is, nevertheless, interesting to note, that the present method affords possibilities of studying tidal boundary waves of so small amplitude, that they would be quite inaccessible to the older technique.

#### ORIGIN OF THE INTERNAL MOVEMENTS.

The central problem offered by these internal movements in the stratified coastal waters is naturally what their cause or causes may be. According to the theory propounded by O. Pettersson,[1] they form part of a *tidal* movement in the boundary, due to those long-periodic components in the tidal force which are denoted by the letters *Mm* and *Mf* in the harmonic analysis of the tides. These components, which are only able to produce minute fluctuations of the free surface should, according to this theory, evoke considerable effects in the slower reactive boundary, which effects may be further enhanced by resonance. By way of lending support to this explanation its author has drawn attention to the fact that the larger "waves" at Bornö very often occur at intervals of a fortnight (or a week), and that a certain train of waves has been found to repeat itself almost unaltered in shape after the lapse of a time equal to a multiple of the periods set out above.

Another explanation has also to be considered which attributes these internal movements to meteorological causes, viz, to variations in the local wind and the air pressure. It is a well-known fact, that a strong air current has a certain influence on stratified water, disturbing the equilibrium and producing a slanting position of the boundary surfaces. The system of currents generated in this manner has been ably studied and described by Sandström.[6]

Disregarding for the present the intricate dynamical part of the problem, we can say that any force which has for its immediate effect an inclination of the free surface will in stratified water tend to produce an inclination to the opposite side of the boundary. Taking the simplest case of a fiord with only two water-strata of the densities $\delta < \Delta$ a constant slope of the surface equal to $\frac{dy}{dx} = C$ produced by a strong wind from the sea will ultimately produce a slope of the boundary of the magnitude $\frac{dy}{dx} = -C \times \frac{\delta}{\Delta - \delta}$. At a given point in the fiord we shall therefore expect the boundary to become finally depressed by the vertical distance $-H = -\frac{\delta}{\Delta - \delta} \times h$, where $h$ is the rise of the free surface above its normal level at the same point.

The factor $\frac{\delta}{\Delta - \delta}$ varies considerably, but its average value is of the order 100 so that elevation of the surface of a few cm. would correspond to a depression of the boundary (at equilibrium) of as many meters. Now for every meter the boundary becomes displaced, roughly fifty million tons of water have to be transported through the orifice of the fiord in both directions. A certain time must therefore pass before the equilibrium value

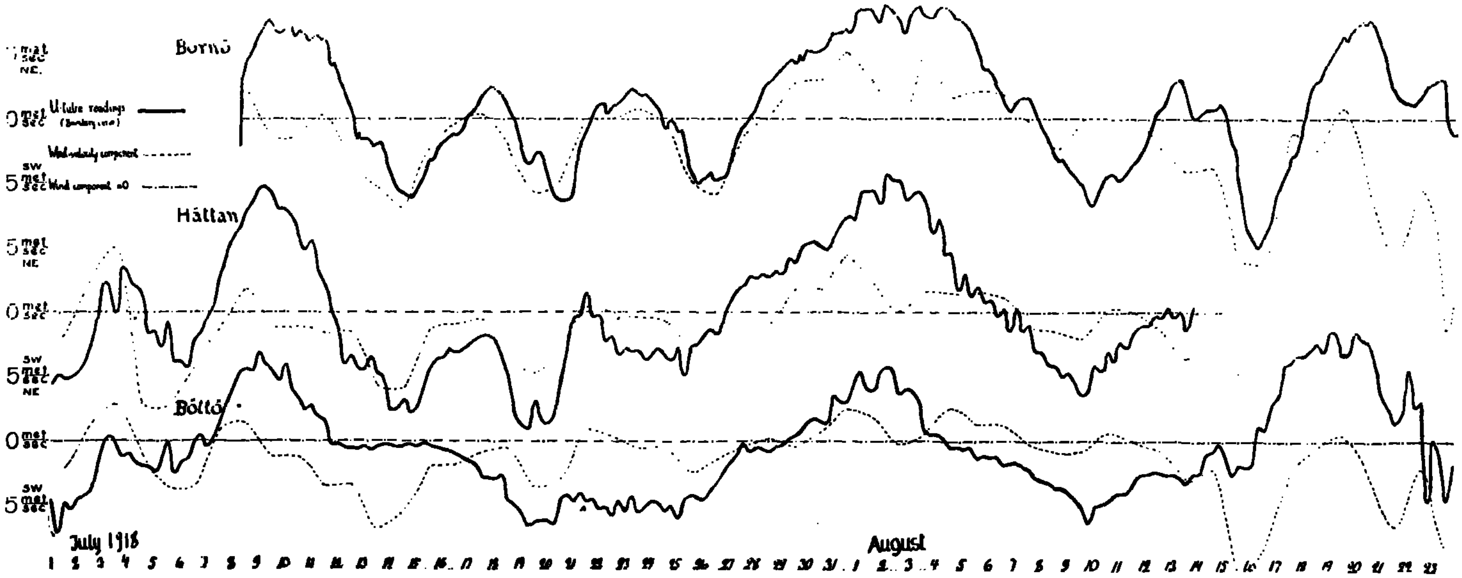


FIG. 3.—Relation of wind direction to the level of the upper boundary of dense sea water.

[5] Svenska Hydr.-Biol. Komm. Skrifter, h. V.

[6] Ann. d. Hydrographie 1908, p. 9.

of the displacement has been (approximatively) attained. The variations in the level of the boundary must therefore inevitably lag behind the variations both of the wind and of the surface level. This lag will, in general, be greater in summer, when the factor $\frac{\delta}{\Delta-\delta}$ is usually small, than in winter when it is much larger.

In order to prove or disprove this meteorological theory, one must compare the boundary curve from Bornö with the simultaneous variations in the wind, or rather in the component of the wind velocity, which is parallel to the main direction of the fiord, i. e., SW. to NE., and also to compare it with the variations in the level of the free surface at Bornö. In order to give any results of value, this comparison must at least be extended over a whole year. I have gone through the rather laborious calculation required for that purpose for the whole of the year 1911, when the observations made at Bornö were more than usually complete. The boundary curve was obtained by calculating from each of the daily hydrographical soundings the depth at which water of 31 per mil salinity was found. For the surface level daily averages were calculated from the records of the maréograph at Bornö. The wind component (daily average) was found graphically from wind observations taken by anemometer three times a day at "Hållö" lighthouse near the entrance to the fiord. The three curves plotted against time are reproduced in figure 5 for the first quarter of 1911. $W$ denotes the wind velocity in meters per second projected on the NE. (positive) to SW. (negative) direction. The surface curve $S$ is drawn inverted, whereas the boundary curve $B$, is drawn in the ordinary way, the scale being 30 times smaller than that of the $S$ curve. The conformity between the three curves is unmistakable, almost every increase in the wind component from the SW. being followed by a rise of the surface (a fall in the inverted curve) and a depression of the boundary. The latter change is, however, seen to be appreciably retarded against the two others. The opposite effect nearly invariably follows after an increase in the component from the NE. These results are in perfect accordance with the reasoning set out above. The same applies to the results obtained for the rest of the year with the exception that in summer the conformity between the $W$ and $S$ curve on one side and the $B$ curve on the other is not so pronounced, whereas the lagging behind of the latter curve is apparently greater.

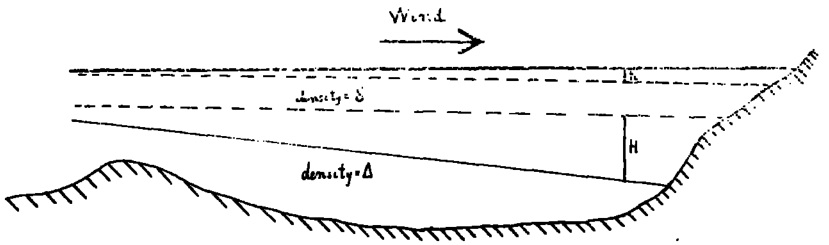


FIG. 4.—Influence of an up-fiord wind in depressing the surface of dense sea water on the bottom.

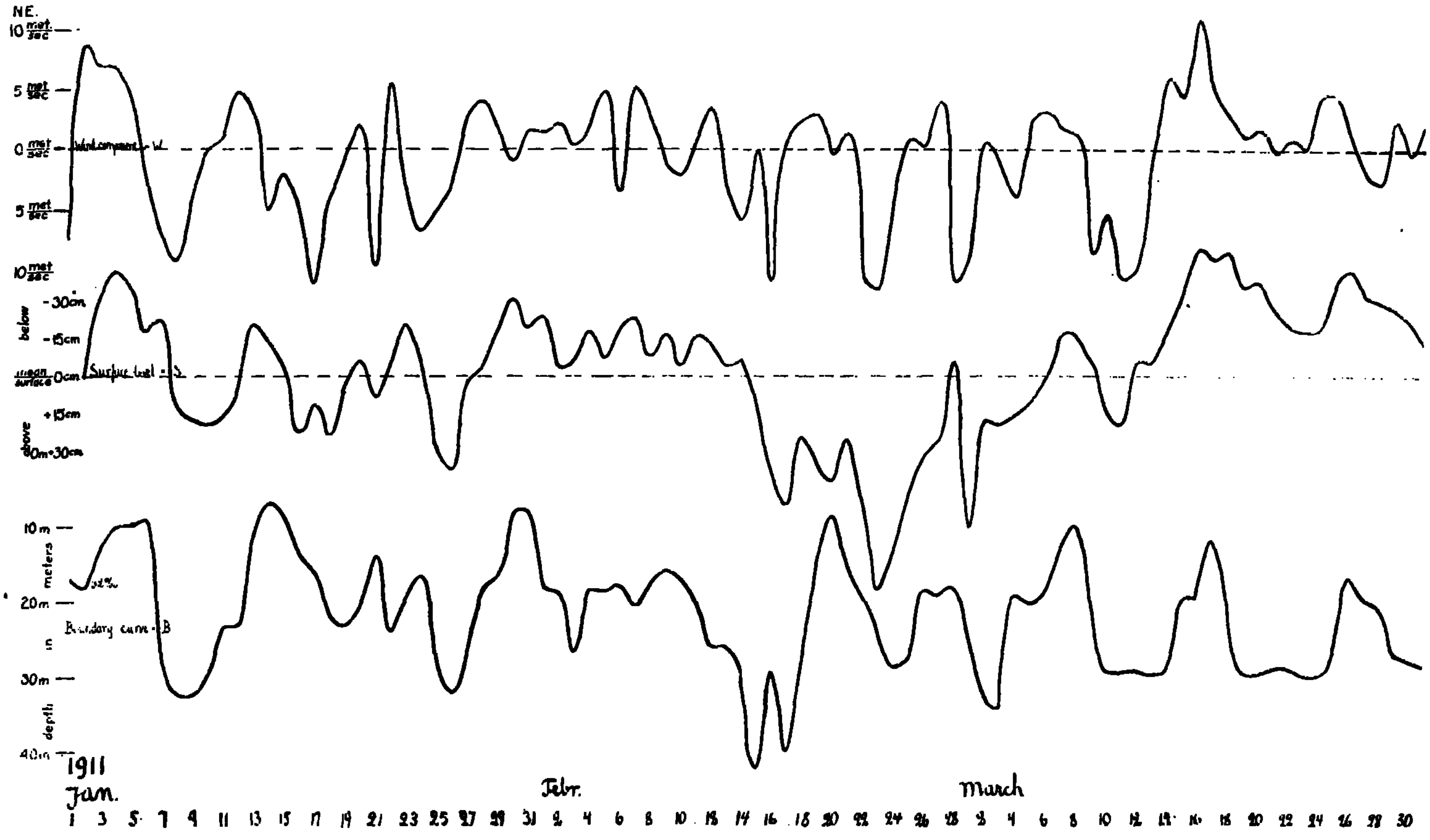


FIG. 5.—Relation of wind velocity to surface and dense sea-water levels.

In order to test the relationship thus established, I have found it desirable to study the conformity by a more objective method. For this purpose I have calculated the correlation coefficients between the $W$ and $B$ curve for each month of the year by the method used by Wallén[1] and others for similar purposes. The results from these calculations show that the correlation coefficient, which is positive and comparatively high, varies from a maximum value in winter to a minimum in summer, the mean value for the months May–October being 0.65 whereas for the rest of the year it amounts to +0.30. The relationship for the summer months is therefore plausible, whereas for the six winter months it is established beyond a doubt.

A similar calculation was also gone through for the barometer pressure compared to the boundary curve. The value and even the sign of the correlation factor thus found varied from month to month, its amount being on the whole so low that the relationship seems rather doubtful.

The details regarding this investigation, which is at present being extended to the years preceding 1911,

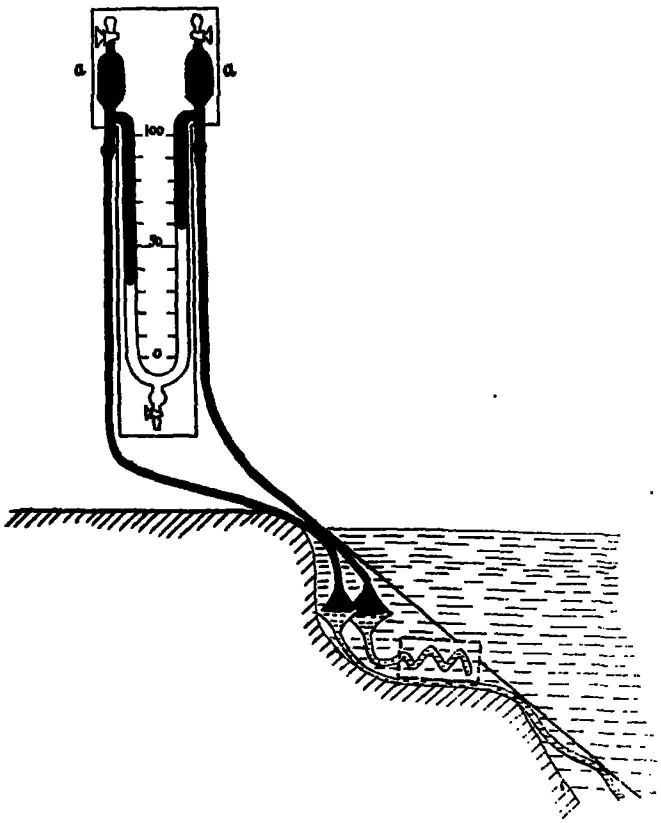


FIG. 6.—Pettersson's hydrostatic densimeter.

must be reserved for a future communication. Its results have, however, already proved beyond a doubt that the remarkable internal movements in the sea observed at Bornö have for one of their principal causes simultaneous variations in the wind velocity. It is of course an open question whether there may also be other influences, tidal or not, at play. The investigation, which is at present in progress may be hoped to throw some light also on this question.

In figure 3, giving the results from the synoptic observations of last summer, curves are also drawn (broken) which represent the NE./SW. component of the wind velocity, as observed at three lighthouses along the coast, viz, at "Hållö" near Bornö, at "Pater Noster" near Hättan, and at "Vinga" nearBöttö. The relationship between the wind velocity and the movements of the boundary is best borne out by the Bornö curve, but is also fairly evident at the two other places. A similar comparison for the winter months would no doubt have given a much closer agreement. One may therefore say that the relationship between meterological phenomena and the internal movements in the sea, which has been discovered in the Bornö records from 1911, is also found to hold for the general movements comprising a considerable part of the coast, according to the results from this synoptic investigation.

Out of the results gained by this preliminary investigation a number of important questions arise. How far along the coasts of the Skagerak and the Kattegat are these internal movements of the same character and of the same phase? Is there really an undulatory element, more or less highly damped, present in these movements? Is the wind component at right angles to the fiord and parallel to the coast of no influence whatever? Why are the variations in the air pressure (which have a well-known influence on the level of the surface) without any apparent effect on the boundary, as the records from 1911 seem to indicate? Apart from these problems there are a number of others bearing on the relationship between the internal movements and biological phenomena, the migration of fishes, the different abundance of plankton in different years (which is probably the cause of the remarkable preponderance of certain year-classes in the catches of many food fishes), all of which require to be cleared up. Evidently these problems can best be attacked by establishing a system of synoptic hydrographical observations at a number of representative localities along the coasts of Sweden, Denmark, and Norway, and by combining this research with a careful study of fishery statistics and growth determinations of fishes and with frequency measurements of the plankton.

A preliminary report on the investigations described in this paper was read before the congress of Scandinavian geophysicists which was held in Gothenburg during the last days of August this summer. At the same meeting a paper was read by Dr. Gaarder of Bergen (Norway) describing some hydrographic measurements made in the Christiania fiord in March, 1916, which also indicate that meteorological changes have an influence on the hydrographical situation.

The following resolution, moved by the author together with Dr. Gaarder (for Norway) and Dr. Jacobsen (for Denmark), was unanimously carried at the final meeting of the congress in pleno:

> The first congress of Scandinavian Geophysicists considers it desirable to establish a system of continuous hydrographical observations of the internal movements in the sea, especially along the coasts of the Skagerak, the Kattegat, and the Belts, both from lightships and from observatories on the coast, the results from this survey to be compared with biological phenomena (fishery statistics and quantitative plankton measurements) and also with observations of the wind and the barometric pressure.

A committee of three (the movers of the resolution) was charged with the drawing up of a detailed program for this survey.

There is little doubt that internal movements in the sea similar to those described in this paper are also going on in stratified waters along the west coast of the North Atlantic. Synoptic investigations in these regions, which might be carried out at comparatively small costs and with little labor, would undoubtedly give results of considerable interest and would yield valuable contributions to the knowledge of the interaction between the atmosphere and the ocean.

[1] Sv. K. Vet. Akad. Handl. Bd. 57, No. 8.

SUMMARY.

Synoptic observations of hydrographic phenomena have been made during July and August of last summer at three different points on the west coast of Sweden. The results prove that internal movements closely resembling those found at Bornö occur practically simultaneously also at distant localities. These vertical displacements of the boundary are found to be closely related to simultaneous variations in the wind velocity, a fact which has also been proved by a separate investigation of the Bornö records for 1911. The establishment of a permanent system of synoptic observations in the sea found the coasts of Scandinavia is at present in progress.

APPENDIX.

The hydrostatic densimeter described in a preceding paper has been modified in the following details so as to be better adapted for localities where sufficiently deep water can only be attained at some distance from the shore, and also to be independant of temperatures far below freezing point. (Fig. 6.) The U tube of glass is mounted upside down with a corresponding change in the position of its air traps $A$, $A$, and communication tubes, to which the submerged tubes are attached. The latter are of lead, one-fourth inch wide, and are supported by bronze wires running along the whole length of the tubes so as to save them from the strain due to their own weight. About 1 meter below the surface there is a biconical brass vessel of about 1 liter inserted in each branch of the system. The upper half of these vessels is filled with liquid paraffin (black in the figure), colored red with a scarlet dyestuff insoluble in water, and the same fluid is contained in the upper part of the system from the vessels and upward. Only the lower half of the U tube itself is filled with a mixture of water and alcohol of the approximate density 0.85 (4 parts of water to 6 parts of alcohol) which serves as index fluid. The sensibility of the system may be varied by taking other concentrations of the water-alcohol mixture (within certain limits). The instrument is quite as easy to mount and to read as the type previously described.

## NOTES ON THE FLUCTUATIONS OF MEAN SEA LEVEL IN RELATION TO VARIATIONS IN BAROMETRIC PRESSURE.

By Capt. T. BEDFORD FRANKLIN.

[Abstract from Jour. Scottish Met'l Soc., vol. 18, 1918, pp. 30-31.]

A study of the data from self-recording tide gauges at Dunbar, Newlyn, and Felixstowe by Col. Sir Charles Close brought him to the following conclusions:

1. That the effect of the local variation of pressure on sea level is opposite in sign to, and 13.25 times the magnitude of, the barometric variation—that is, the ratio is the same as the ratio of the specific gravity of mercury to that of sea water. [The actual ratio varies from about 7–20.]

2. That there is an annual tide—the cause at present unknown—having an amplitude of 6 inches, with a maximum in November and a minimum in April.

As suggested in 1914 by Prof. D'Arcy W. Thompson, the discrepancies between the tidal variation and barometric curves may be accounted for by considering atmospheric pressure and winds together. For Newlyn, by assuming that the effect of the wind either in piling up the water or in pushing it out to sea is proportional to its pressure in pounds per square foot, such that the effect in inches of sea level is about 1.5 times the inshore or offshore component of the wind pressure, it is possible to account closely for the differences between the hydrostatic and observed effects. This effect on seven occasions cited was 1 to 7.5 inches.

It would, therefore, appear that by applying the appropriate wind correction the two curves may be made very nearly to fall upon each other, and that for the limited period under observation—December, 1916, to June, 1917—*the sea level responded immediately to the combined influences of barometric pressure and wind.*

## THE EFFECT OF WIND ON SEA-LEVEL.

[Extract from Nature (London) Feb. 13, 1919, p. 471.]

* * * Changes of level due to winds cause some fluctuation in individual estimates of the ratio (from 7 to 20, roughly), but not sufficiently to mask the close connection between sea-level and barometric pressure.

In a narrow landlocked sea, however, it might be expected that the wind would have relatively greater influence, and this is confirmed by a recent study of the Baltic sea level by Rolf Witting (*Öfv. af Finska Vet.-Soc. Förh.*, vol. lix, A, 13. Helsingfors, 1917). The purely hydrostatic effect of a gradient of barometric pressure over any region is to produce an opposite slope of the sea surface; but such a distribution of atmospheric pressure is usually accompanied by winds directed along the isobars, with the higher pressure on the left (in the Northern Hemisphere). This tends to heap up the waters with a gradient perpendicular to the former one, and in the Baltic this slope appears to be about 1.8 times as great as the hydrostatic slope. The resultant gradient is rather more than twice the latter and is inclined to it in azimuth at about 55°.

## AN INSTRUMENT FOR ACCURATE AND RAPID DENSITY MEASUREMENTS ON BOARD SHIP.

By A. L. THURAS.

[Author's summary, from Journ. Wash. Acad. Sci., 1917, 7: 605-612, 2 figs.]

A simple apparatus is described by which the density of sea water can be measured on board ship with speed and precision. With carefully calibrated bobbins a density measurement of a liquid of known temperature coefficient can be made in less than 10 minutes to an accuracy of more than two in the fifth decimal place. The particular advantage of the method lies in the facts that (1) by changing the temperature of the liquid its density can easily and quickly be brought exactly to the density of the bobbin, and (2) at equilibrium temperature the sensitivity of the method is unaffected by the motion of the vessel, the liquid and bobbin having the same density.

## AN ELECTRICAL INSTRUMENT FOR RECORDING SEA-WATER SALINITY.

By ERNEST E. WEIBEL and ALBERT L. THURAS.

[Author's summary, from Journ. Wash. Acad. Sci., 1918, 8: 145-153, 3 figs.]

An apparatus to give a continuous record of sea-water salinity by the measurement of its electrical conductivity is described. A pair of electrolytic cells has been designed which when used with a suitable alternating-current galvanometer will give satisfactory operation in connection with a recorder. The temperature compensation is obtained by placing both cells, which are in the